Solar Physics at Nançay Radio Observatory : Recent Developments

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Abstract

The Nançay station of Paris Observatory operates two key instruments for solar physics: the *Decametre Array* (dynamic spectra of bursts, 20-70 MHz) and the *Radioheliograph* (images in the 150-450 MHz range). A new spectrograph (130-1000 MHz) is under construction for scientific and space weather purposes. This contribution summarises the performances of the instruments and illustrates recent results on the quiet Sun, quasi-continuous particle acceleration in active regions (noise storms) and radio observations relevant to coronal mass ejections and solar energetic particle events. These observations will be an essential support in future investigations of the Sun-Heliosphere connection with *Solar Orbiter* and *Solar Probe*.

1 Introduction

Radio emission is a tracer of the thermal plasma and of transient phenomena in the solar atmosphere related to energetic electrons. The Nançay Observatory is pursuing a long standing tradition in solar radio observations using spectrography and imaging from decimetre (dm) to decametre (Dm) wavelengths (Sect. 2). These observations provide on the one hand diagnostics of the thermal plasma complementary, *e.g.*, to EUV spectroscopy (Sect. 3.1). On the other hand dm-Dm wave radio emission is extremely sensitive to non thermal electrons even in the absence of flares (Sect. 3.2). Radio bursts produced by electron beams and other unstable distributions are an important diagnostic of electron acceleration and propagation in the tenuous corona, and give a unique contribution to the investigation of solar energetic particles in interplanetary space (Sect. 3.3).

2 Solar Physics Instrumentation at Nançay Observatory

The *Nançay Decameter Array* (NDA; 6) is an antenna array that takes dynamic spectra of the Sun in the 20-70 MHz range with very high sensitivity at sub-second time resolution. It provides a minimum observing time of 8h/day on the Sun, and observes also planetary and galactic sources. The *Nançay Radioheliograph* (NRH; 3) is an aperture synthesis array that has been carrying out imaging observations at a number of frequencies in the range 150-450 MHz since July 1996. It is still the only solar-dedicated instrument in the world in this range. The performances have been continually upgraded, from an initial time resolution of 2 images per second at five frequencies to 4 images per second at 10 frequencies in recent years. There is a trade-off between the number of frequencies and time cadence.

The receivers of both instruments are being upgraded. In order to extend the spectral observation to higher frequencies, including the range of NRH, a new radio spectrograph is presently built in the range 130-1000 MHz. It will provide routine observations starting September 2011. This is a project in cooperation with the French Air Force, aimed at providing patrol observations with rapid data transmission for space weather purposes. The data will be public.

A combined data display and data access system of NRH, NDA and the Greek ARTEMIS spectrograph with the space borne *Wind*/WAVES and STEREO/WAVES spectrographs has been elaborated by M. Pick and coworkers in Meudon. Browser data and access to data is available at `http://secchirh.obspm.fr/`.

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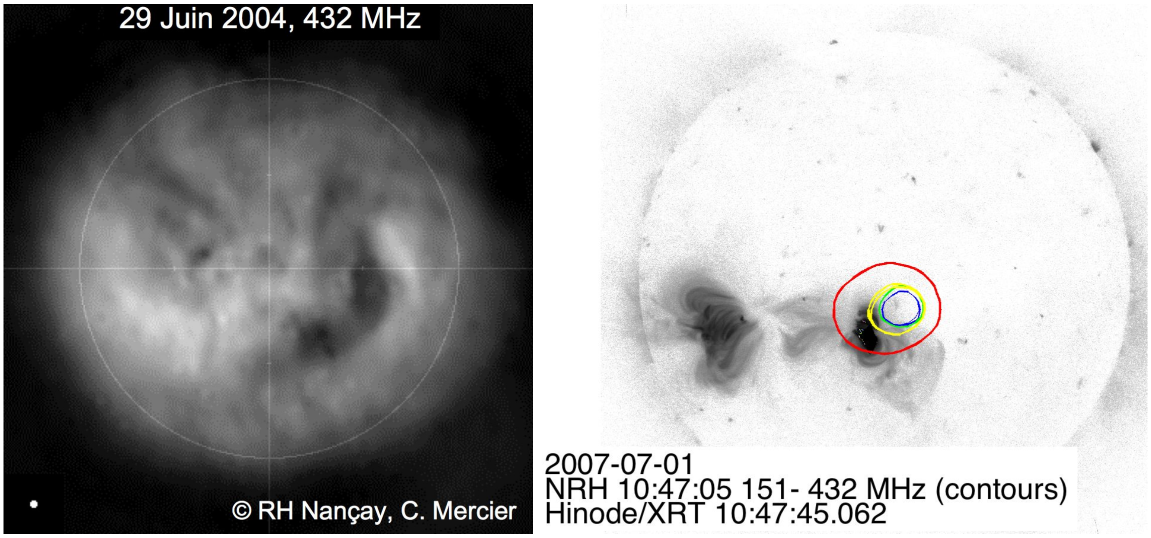

Figure 1: The non flaring solar corona at radio wavelengths seen by NRH. *Left*: quiet corona. *Right:* noise storm (contours) superposed on a *Hinode* X-ray image in inverse colour scale (2). Solar north is at the top, west on the right side.

3 Recent Scientific Results

3.1 The quiet solar corona

The quiet corona is a radio emitter through thermal bremsstrahlung. At dm and m wavelengths the emitting plasma extends from the low corona to about half a solar radius above the photosphere. While imaging using aperture synthesis arrays was carried out in the past by the Culgoora Radioheliograph, NRH, the VLA, and others, systematic studies are still lacking. Radio emission is in principle a valuable diagnostic of the electron density and the electron temperature. The emission process is well understood and does not critically depend on assumptions on atomic states that affect, *e.g.*, EUV line emission. But the exploitation of the radio diagnostic requires careful calibration of the instrument, which has been a limitation in the past. The addition of four antennas to the NRH array in 2003 considerably reduced the earlier problems with aliasing. C. Mercier and G. Chambe (8) revised the calibration procedure and started an in depth analysis of quiet Sun observations with the NRH to produce Earth-rotation synthesis maps of the quiet corona.

An example is shown in the left panel of Fig. 1, displaying the corona observed at 432 MHz. The plasma is seen to be highly structured at this frequency. A prominent feature is the low-latitude coronal hole visible as a brightness depression in the western hemisphere (right side of the disk in this picture). Other depressions in the north-eastern quadrant and near the north pole are also due to low density regions in filament channels (7). A systematic quantitative analysis of these observations is underway.

3.2 Electron acceleration in quiescent active regions: noise storms

Noise storms are the most frequent radio emission at metre wavelengths associated with active regions. They can last for hours or even days, while the parent active region crosses the solar disk. The emission can reach brightness temperatures of a few 10^8 K, and is usually strongly circularly polarised. Because of these properties noise storms are ascribed to non thermal electrons, whose energy was estimated of order a few keV (11), but is actually poorly known. The long duration and lack of correlation with solar flares make noise storms a prime example of quasi-continuous electron acceleration in quiescent active regions.

Since there are few specific associations, the circumstances under which electrons are accelerated is still poorly understood. The acceleration must be related to the evolution of the coronal magnetic field, since noise storms arise in phases of characteristic changes of the large-scale magnetic field such as the establishment of an interconnection between different active regions (12). Flare-like features are observed at the onset of noise storms as soft X-ray brightenings (11), but without an Hα signature that would qualify these events as flares. The energy release must be of magnetic origin: it was indeed shown by combined NRH, SoHO and TRACE observations that noise storms arise above regions of changing photospheric magnetic field (1).

A recent analysis of two active regions that presented persistent outflows and noise storms, combining *Hinode*/EIS and NRH observations with the modelling of coronal magnetic fields (2), shed new light on the region of the electron acceleration at the origin of noise storms. True separatrices were identified in the coronal field, and null points high in the corona. It is suggested that the continuous growth of active regions maintains a steady reconnection across the separatrices at the null point. This interchange reconnection occurs between closed, high-density loops in the core of the active region and neighbouring open, low-density flux tubes. The reconnection creates strong pressure imbalances, which are the main drivers of plasma upflows. The acceleration of low-energy electrons in the interchange reconnection region sustains the noise storm in the closed loop areas, and weak type III emission along the open field lines, which is seen in NDA spectra as the low-frequency counterpart of the noise storms. The observed places of persistent coronal outflows and noise storms are found to be remarkably consistent with those predicted by this interpretation.

3.3 Radio emission as tracer of coronal and interplanetary particle propagation and coronal mass ejections

Type III radio bursts are generated by electron beams at typical energies of a few keV through a beam-plasma instability, which produces Langmuir waves that subsequently convert to electromagnetic waves. These waves give a characteristic track in the frequency-time plane consisting of a short burst that drifts towards lower frequencies as the exciting beam propagates through an ambient medium with decreasing density, hence decreasing plasma frequency. These bursts are an extremely valuable tracer of charged particle propagation from a coronal acceleration site through the corona and interplanetary space, and therefore a precious diagnostic for the study of the origin of solar energetic particles (SEP) detected in space.

The mapping of type III bursts in the corona identifies open magnetic field lines along which electrons proceed to interplanetary space. A comparative study using the NRH and potential magnetic field extrapolations of SoHO/MDI observations (code provided by C. Schrijver and M. Derosa) showed a consistent identification of the open magnetic fields rooted in flaring active regions with these methods (5). The first combined observations of the NRH with the SECCHI coronagraph aboard STEREO clearly confirmed that the type III emitting electrons propagate along open structures seen in coronagraphic images, and extended earlier work to greater heliocentric distances (9). The open field lines are often far from radial, but diverge rapidly with increasing heliocentric distance, because there is less and less confining closed magnetic flux with increasing altitude. As a result, these diverging field lines may connect an active region to the Earth-connected interplanetary field line in the high corona even if the parent active region is several tens of heliocentric degrees away from the nominal Parker spiral (5). SEP can hence be observed near the Earth even if the parent activity is far from the nominal footpoint of the Parker spiral.

Another means to inject SEP onto interplanetary field lines that are poorly connected with the Earth is provided by large-scale disturbances associated with flares and CMEs, so-called 'EIT waves'. Recent combined work with STEREO and the NRH showed that individual successive type III bursts may come from sources that are progressively displaced from the flaring active region and seem to reveal acceleration processes that occur at the interface of the propagating large-scale disturbance and the ambient corona (4).

A series of studies using the NRH, NDA and other spectrographs has now shown that the complex long lasting radio emission associated with coronal mass ejections (CMEs) is able to trace the spread of the CME activation in the low corona (see Fig. 115 of 10, and references therein). This is an important tool for the investigation of the mechanism involved in the early phase of CMEs and on their role in the acceleration and propagation of energetic particles during these large events.

4 Conclusion

Nançay Radio Observatory remains a very valuable site for solar observations at dm-to-Dm waves. The existing equipment is being upgraded, and data distribution procedures are being improved. There is a range of applications to space weather activities that will be developed. The main scientific motivation in the coming years will be the coordinated effort to elucidate the connections between the Sun and the Heliosphere, through the determination of basic parameters of the quiet coronal structures from which the solar wind originates, and through the tracking of coronal disturbances that penetrate into interplanetary space and will be measured *in situ* from close vantage points by the *Solar Orbiter* and *Solar Probe* missions. The ground-based radio observations are a necessary tool to guarantee the scientific return of these major projects of solar-terrestrial science.

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